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Cognition in Children Does Not Suffer From Very Low Lead Exposure

Barbara Minder, Edith A. Das-Smaal, and Jacob F. Orlebeke

Abstract

We studied the relationship between exposure to lead and memory and attention in children. Participants were 313 boys aged 9 to 12 years who attended special education schools in the Netherlands. Children whose possible attentional or memory problems were obviously due to causes other than lead contamination were excluded from the study. Cognition was assessed by extensive theory-based testing. Blood lead concentration was measured to assess body lead burden. Possible confounding factors that might affect blood lead level and/or cognitive functioning were assessed. Blood lead levels were higher in children with lower socioeconomic status and in children with more hand-to-mouth behavior, and varied seasonally, with higher values in spring and summer. The mean blood lead level was 44.4 microgram lead per liter blood, which is considered low. Only 2% of the children showed a slightly higher blood lead level than the American safety standard. To obtain robust measures of cognitive aspects, we performed a factor analysis. The results showed that blood lead level did not influence any of the cognitive factors. Therefore this study, despite being designed to maximize the chance of finding an effect in asymptomatic children, does not support a relationship between lead at very low doses (below 100 micogram/liter blood) and cognition in schoolchildren.

The effect of low level lead exposure in children has been extensively investigated. It is now generally accepted that lead at low doses may influence behavior in children. Body lead burden is usually assessed by blood lead concentration. Although the burden of lead in children has decreased considerably in recent years, it has not been determined at which blood lead level no neurotoxic effects can be detected. In 1969 a blood lead level of 600 μg/L was thought to be safe in the U.S. Gradually, this limit has been lowered to 100 μg/L blood in 1991. Whether this level of 100 μg lead per liter blood is safe or still too high remains an issue of debate (Needleman & Jackson, 1992; Sayre & Ernhart, 1992; Schoen, 1993; Smith, 1989). As an extreme point of view Flegal and Smith (1992) proposed that the natural concentration of lead in preindustrial humans should be taken as a reference value in establishing the safe body lead burden. Their estimate of the blood lead concentration in preindustrial humans was 600 times lower than the safe level of 100 μg/L blood currently recommended.

The kinds of effects lead can induce—decrease of intelligence, attentional deficits, and hearing loss—are generally accepted. Needleman and Gatsonis (1990) performed a meta-analysis on 24 cross-sectional studies on low level lead exposure relative to IQ of children and strongly supported the hypothesis that lead impairs IQ at low doses. Prospective studies in different populations with different exposure levels and in different age groups have demonstrated a reduction in IQ resulting from low level lead exposure (Baghurst et al., 1992; Dietrich et al., 1993; Fulton et al., 1987; Green & Ernhart, 1993; McMichael et al., 1988). Thacker, Hoffman, Smith, Steinberg, and Zack (1992) reviewed 35 reports on prospective studies in children from birth to the age of 58 months. Although differences in methodology and statistical issues made comparing the studies difficult, they suggested that lead adversely affected intelligence in children until at least that age.

Even small changes in IQ scores could imply substantial changes in basic cognitive functions (Bellinger & Needleman, 1992). Needleman et al. (1979) showed that hyperactivity and deficits in cognitive processes such as memory and attention determine the correlation between lead and IQ. More hyperactive behavior and a decrease in attentional capacities were demonstrated in children with higher body lead burden (Needleman, 1990; Needleman et al., 1979). Many of these studies used only behavioral measures derived from parent or teacher questionnaires.

What are the basic deficits underlying an IQ reduction and attentional problems in lead-exposed children?

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These deficits may become clearer when accurate measurements of specific behavioral aspects are used. For this purpose, we have studied the relationship between lead exposure and several measures of memory and attention. In a pilot study we found that children with relatively high concentrations of lead in their hair reacted significantly slower in a simple reaction time task and were less flexible in changing their focus of attention than children with relatively low concentrations of lead in their hair (Minder, Das-Smaal, Brand, & Orlebeke, 1994). To further investigate this issue, another study was carried out in a larger sample of schoolchildren in the Netherlands.

The correlation between body lead burden and cognitive performance is a very weak one when measured in samples representative of the whole population. Nevertheless, even a small effect in the whole population may not be without socioeconomical consequences. Therefore, to maximize the chance of finding any effect, in the previous study as well as in this study children were selected in advance from a group of children with learning and educational problems, for which they were attending a special education school. These schools serve a substantial group of children with attentional problems, and for many the cause of their problems remains unidentified. The selection of children required screening in advance for possible causes of attentional problems other than ecological factors, but not for attentional problems themselves (Minder et al., 1994). These attentional problems were measured later in the testing procedure. Because boys show attentional problems more often than girls (American Psychiatric Association, 1987), only boys participated in this study. Participants were 9 to 12 years of age, to guarantee some stability in cognitive functioning.

We hypothesized that for the children with attentional problems in this group, lead might play an important role in the etiology. It was expected that the effect of lead would show up in attentional disturbances, especially in particular aspects of attention. Based on our pilot study, reaction time seemed to be implicated.

Recent models of attention stress its central role in the control aspect of information processing (Navon, 1989a, 1989b; Neumann, 1987; Norman & Shallice, 1986). However, commonly used attention tests often appear to measure speed of information processing rather than attentional control (de Jong & Das-Smaal, 1993). In this study, speed and control aspects were measured separately. We used the Working Memory model of Baddeley (1986), combined with the Supervisory Attentional System (SAS) suggested by Norman and Shallice (1986), as well as the Additive Factor Method of Sternberg (1969), as a theoretical framework for memory and attention.

According to Baddeley (1986), Working Memory is a multimodal system to temporarily store, manipulate, and process information in cognitive tasks. In his model, he proposes a supervisory controlling system called the Central Executive (CE), which selects, controls, and coordinates the information and processes at hand. The CE is modality-free and limited in its capacity. It regulates several lower order subsystems, so-called slave systems, whose function is to temporarily retain information. These slave systems are modality-specific and limited both in the amount of information they can retain and the duration they can do so. Baddeley gives evidence for two of these slave systems, the Phonological Loop and the Visuo-Spatial Scratch Pad, for the storage of verbal material and visuo-spatial images, respectively.

Attention, according to Baddeley (1986), can be regarded as the efficiency of the CE, that is, the efficiency of the control and coordination of information processing for the task to be fulfilled. As a model for the CE, Baddeley suggests the Supervisory Attentional System (SAS) in the Information Processing model of Norman and Shallice (1986). In this model, a sequence of mental activities is represented by a series of schemas that are run off successively. This process can be automatic or controlled. The automatic system is based on routine and is always active. The controlling system is called the SAS. It is active in non-routine situations, influencing the activities of the automatic system. In this model, the role of attention is the regulation of processes involved in both mental and physical activities. The SAS, like the CE, has a limited capacity. According to Shallice (1982) and Baddeley and Wilson (1988), a dysfunction of the SAS or the CE implies an impairment of the control function of attention. The automatic routine behavior, however, will not be disturbed. So the role of attention is to actively control and coordinate information and procedures.

Besides attentional control, another dimension of individual differences in attention seems to concern speed of information processing (Brand, Das-Smaal, & de Jong, 1996; de Jong & Das-Smaal, 1993). Therefore in this study several speed aspects were measured. To further specify stages in information processing, the memory search paradigm based on the Additive Factor Model of Sternberg (1969) was used. With this model different successive processing stages can be distinguished: encoding, central processing, and response selection. These stages are supposed to be independent of each other, each stage receiving information from the previous one. The total reaction time in an information processing task is considered as the sum of the reaction times of the separate stages.

Method

Participants

Participants were boys aged 9 to 12 years, from special education schools. Some categories of children were excluded from the study: Children with a history of pre- or perinatal complications, serious infections, feverish convulsions, acute poisoning, concussion or head trauma, meningitis, or frequent otitis media; children on medication; children having crude physiological, visual, auditory, or motor defects; and children with emotional problems. Also excluded were children with any of the following in their family history: a hereditary factor for attentional problems (i.e., parental attention-deficit/hyperactivity disorder), obvious lack of educational opportunity, low socioeconomic status (SES), or problems at home. Finally, the child's IQ had to be within the range of 80 to 130. The selection was made by parent questionnaires, teacher reports, and psychological files at school. Of the 565 boys that were screened, 252 were excluded from the study. A total of 313 boys from 30 different schools participated in the study. Their mean age was 10.9 years.

Materials and Procedure

Tests were chosen to measure aspects of the Working Memory model of Baddeley (1986). In addition, a variety of speed tests were administered.

The following tests were employed:

Simple Reaction Time task. Participants were asked to react as fast as possible to the appearance of a square on the computer screen by pushing a button. In addition to mean RT, fluctuation in speed was calculated and expressed as the within-subject standard deviation (*SD*) of RT. RT = speed, SDRT = variability.

Block Task compatible. The children were asked to react as fast as possible to the appearance of a block on the left or right side of a computer screen by pushing the corresponding left or right button. BB = speed, SDBB = variability.

Block Task incompatible. The same as the previous task, but the child had to push the left button if the target appeared at the right side of the screen and the right button if the target appeared on the left side. IB = speed, SDIB = variability.

Digit Span forward. A series of digits increasing in length were presented by taperecorder. Digits were presented with a 1-second interval. The child had to repeat the digits in the same order. DSF = amount of digits correctly recalled.

Digit Span backward. The same as Digit Span forward, but the digits had to be repeated backward. DSB = amount of digits correctly recalled.

Digit Span sequence. The same as Digit Span forward, but the digits that were included in the series had been mentioned in advance in their regular order. DSS = amount of digits correctly recalled.

Letter Span, phonologically the same or different. A series of letters increasing in length were given by taperecorder. Letters were presented with a 1-second interval. The letters were phonologically the same in one subtest, and phonologically different in the other subtest. The child had to repeat the letters in the same order. LSS and LSD respectively = number of letter series correctly recalled.

Counting Span forward. On a computer screen, a series of simple additions and/or subtractions (e.g. 5 + 1, 3 – 1, etc.) were presented. The sums were given one by one for a short period of time. Each answer had to be retained. At the end of the series the answers (digits) had to be given in the same order as the sums. CSF = number of correct answers.

Counting Span backward. The same as Counting Span forward, but the answers had to be reproduced backward. CSB = number of correct answers.

Trail Making Test A and B. Circles containing digits from 1 to 15 scattered over a piece of paper had to be connected as quickly as possible (test A). In test B the child had to alternately connect circles with digits and letters in counting order and alphabetical order. TMTA and TMTB respectively = time to complete trail.

Trail Making Test revised. Essentially the same task as above, the difference being that participants chose the digits or letters each time from a row of three digits or letters. In this way the search factor was less pronounced. TMTRA and TMTRB = total of choices made in two minutes.

Sternberg task. The speed of information processing in working memory was measured. Probe and targets were digits projected one by one on a computer screen. Each probe had to be compared with 2 or 4 targets that were kept in memory. Part of the targets were presented in a degraded way. NOR2 = 2 targets undegraded, DEG2 = 2 targets degraded, NOR4 = 4 targets undegraded, DEG4 = 4 targets degraded.

Brus Reading Speed task. In one minute words had to be read as fast as possible. BRS = number of words correctly read.

Raven task. On paper a set of geometrical figures were presented. These figures were grouped by some rule. Participants had to find the rule(s) and to choose the last figure for each set according to this rule. RAV = number of incorrect answers.

Bourdon-Vos task. On a paper with a series of dot figures containing either three, four, or five dots the child had to check all figures with four dots. BOUR = number of responses in two minutes.

The origins of the tests, the psychological aspect they intend to measure, and the kinds of scores derived from them are summarized in Table 1.

The Raven and the Bourdon-Vos tests were administered in small groups of about seven children. The other tests were given individually, always in the same sequence, and in two sessions on different days. These sessions were kept as close together in time as possible, and always within three days and at the same time of day. Each session took about 50 minutes. In the first session the tests were administered in the following order: Simple Reaction Time, Block Task compatible and incompatible, Digit Span forward and backward, Trail Making A and B, Trail Making revised, Digit

TABLE 1
Tests Used in the Study

Test	Origin/ reference	Aspects of psychological functioning	Measure
Simple Reaction Time	NES	visuo–motor function processing time	speed variability
Block Task compatible/ incompatible	NES	speed of information processing/speed of information processing and response inhibition	speed variability
Digit Span forward/ backward	WISC-R	Ph-loop (storage)/ Ph-loop and CE function (storage and processing)	accuracy
Digit Span sequence	WISC-R	Ph-loop function	accuracy
Letter Span phonologically same/different	Conrad & Hull (1964)	Ph-loop function interference	accuracy
Counting Span forward/ backward	Das-Smaal, de Jong, & Koopmans (1993)	Working Memory function	accuracy
Trail Making A & B	Reitan & Davidson (1974)	visual search, CE function	speed
Trail Making A & B revised	Das-Smaal, Brand, & Van den Hooff (1990)	CE function	speed
Sternberg	Sternberg (1969)	encoding, central processing, response selection	speed
Brus Reading Speed	Brus & Voeten (1979)	phonological coding, naming	speed
Raven	WISC-R	Working Memory function	errors
Bourdon-Vos	Vos (1988)	visual coding	speed

Note. WISC-R = Wechsler Intelligence Scale for Children–Revised (Wechsler, 1974); NES = Neurobehavioral Evaluation System (Emmen et al., 1988); Ph-loop = Phonological loop. CE = Central Executive.

Span sequence. In the second session the tests were ordered as follows: Brus, Letter Span, Counting Span forward and backward, and Sternberg.

The Estimation of Body Lead

With parental consent, blood samples from each child were taken at school by venipuncture. The children received a present to thank them for their participation.

The blood samples were analyzed using Atomic Absorption Spectrometry (AAS) at the Institute for Environmental Studies of the Vrije Universiteit Amsterdam. Hemoglobin levels were measured by the University Hospital.

Assessment of Possibly Confounding Factors

The body concentration of zinc and iron could confound lead measurements. Therefore, zinc, iron, and hemoglobin were also measured in the blood of the children. Other potentially confounding factors were assessed using school records and parent questionnaires. Potential confounding factors were as follows: IQ of the child, parents' age at the time the child was born, breastfeeding, birth order, family size, single-parent or two-parent family, parents' education, parents' smoking habits, number of rooms in the house relative to the number of inhabitants, rearing styles, television viewing habits, sleeping habits, restless behavior, and mouthing behavior of the child.

Results

Statistical analyses were carried out with SPSS-PC V3.1 software and LISREL 8.1. To determine group differences, *t*-tests were used.

Blood Lead Levels and Other Blood Measures

The mean blood lead concentration of the children was 44.4 microgram per liter blood (SD = 22.0). Lead concentration range was 8.0–160.0 μg/L. Because the distribution of blood lead concentrations was positively skewed, a logarithmic transformation was performed. All subsequent analyses were made with these transformed data.

The mean concentration of zinc in blood was 12.2 μmol/L (SD = 2.2), of iron 16.5 μmol/L (SD = 5.1), and of hemoglobin 8.5 μmol/L (SD = 0.5). These values were all within the normal range.

Blood Lead Levels and Confounding Factors

No significant correlation was found between lead concentration and the age of the children. A lower socioeconomic status seemed to be associated with a higher blood lead level ($r = .11$; $p < .05$). Children who sucked their thumb and/or bit their nails had higher blood lead levels than children who did not (t = –2.48, df = 244, p = .014). Furthermore, children had higher blood lead levels in spring and summer than in autumn and winter (t = –2.71, df = 308, p = .007). No other confounding factors correlated with blood lead level.

Blood Lead Levels and Cognition

All subjects who scored more than three times the standard deviation on a task, or who were unable to perform a task, were excluded from the analysis for that task.

There were no significant correlations (p >.05) between test results and blood lead levels. To establish more powerful measures of the different aspects of information processing, an exploratory and a confirmatory factor analysis were performed on the tests. List-wise deletion of cases where values are missing is inherent in factor analysis. Therefore the test results of 279 subjects were included in the final analysis. Five factors could be identified in the exploratory factor model. The factors were converged by varimax rotation. Table 2 shows the factor loadings for the test variables that loaded at least .40 on a factor.

TABLE 2
Factor Loadings of the Tests

	Phonological loop	Reaction time	Memory search	Perceptual speed	Working Memory
NOR2	–.11	.17	**.82**	–.14	.04
DEG2	–.10	.23	**.84**	–.14	.07
NOR4	–.09	.10	**.85**	–.12	.08
DEG4	–.09	.11	**.80**	–.11	.05
RT	–.12	**.82**	–.03	–.09	.09
BB	–.13	**.76**	.26	–.26	–.13
IB	–.18	**.76**	.28	–.22	–.03
SDRT	.07	**.64**	.02	.04	.40
SDBB	–.13	**.76**	.15	–.12	–.00
SDIB	–.10	**.52**	.37	–.17	–.07
DGF	**.72**	–.04	.02	.08	–.05
DGB	**.44**	–.07	–.13	.21	**–.49**
LSS	**.81**	–.14	–.02	.01	–.01
LSD	**.80**	–.14	–.02	.01	–.01
DGS	**.69**	–.06	–.10	–.04	–.10
CSF	**.61**	–.08	–.15	.19	–.12
CSB	**.48**	–.03	–.19	.17	–.18
BRS	**.49**	–.15	–.05	.17	.18
BOUR	–.02	–.04	–.14	**.63**	.04
TMTA	–.12	.21	.03	**–.69**	.01
TMTB	–.08	.18	.05	**–.65**	.36
TMTRA	.28	–.19	–.21	**.69**	–.03
TMTRB	.23	–.07	–.15	**.75**	–.24
RAV	–.13	.00	.09	–.17	**.76**

Note. NOR2/DEG2 = Sternberg task, two targets undegraded/degraded; NOR4/DEG4 = Sternberg task, four targets undegraded/degraded; RT = Simple Reaction Time task; BB/IB = Block task compatible/incompatible; SDRT = standard deviation Simple Reaction Time task; SDBB/SDIB = standard deviation Block task compatible/incompatible; DGF/DGB/DGS = Digit Span forward/backward/sequence; LSS/LSD = Letter Span phonologically the same/different; CSF/CSB = Counting Span forward/backward; BRS = Brus Reading Speed task; BOUR = Bourdon-Vos task; TMTA/TMTB = Trail Making Test A/B; TMTRA/TMTRB = Trail Making Test A/B revised; RAV = Raven task. Boldface type indicates loadings > .40.

Factor 1 reflects the phonological loop function in Baddeley's (1986) Working Memory model, Factor 2 reaction speed and variability of reaction time, Factor 3 speed of memory search, Factor 4 perceptual–motor speed, and Factor 5 Working Memory function, especially the functioning of the Central Executive. In accordance with the theoretical model, separate attentional control and speed factors were identified.

The five latent factors of the exploratory factor model were used as a starting point for the construction of a confirmatory factor model. Two attentional control factors were assumed, in congruency with the Working Memory model of Baddeley (1986): the Central Executive and the phonological loop function. The speed aspect comprised three factors: reaction speed, perceptual–motor speed, and speed of memory search. The Brus reading test seemed too complex to be assigned to one specific factor on theoretical grounds. Also, the variability of reaction time in the Block compatible and incompatible tasks obtained factor loadings too diverse to be interpretable. Therefore, these three measures were excluded from the confirmatory analysis.

The remaining tests were allowed to load on one factor only. Loadings were assigned based on the exploratory model and theoretical considerations from the Working Memory Model of Baddeley. The chosen loadings of the tests on the latent factors are shown in Table 3.

TABLE 3
Allowed Factor Loadings of the Tests in the Confirmatory Factor Model

	Phonological loop	Reaction time	Memory search	Perceptual speed	Working Memory
NOR2	—	—	1	—	—
DEG2	—	—	1	—	—
NOR4	—	—	1	—	—
DEG4	—	—	1	—	—
RT	—	1	—	—	—
BB	—	1	—	—	—
IB	—	1	—	—	—
SDRT	—	1	—	—	—
DGF	1	—	—	—	—
DGB	—	—	—	—	1
LSS	1	—	—	—	—
LSD	1	—	—	—	—
DGS	1	—	—	—	—
CSF	—	—	—	—	1
CSB	—	—	—	—	1
BOUR	—	—	—	1	—
TMTA	—	—	—	1	—
TMTB	—	—	—	1	—
TMTRA	—	—	—	1	—
TMTRB	—	—	—	1	—
RAV	—	—	—	—	1

Note. NOR2/DEG2 = Sternberg task, two targets undegraded/degraded; NOR4/DEG4 = Sternberg task, four targets undegraded/degraded; RT = Simple Reaction Time task; BB/IB = Block task compatible/incompatible; SDRT = standard deviation Simple Reaction Time task; DGF/DGB/DGS = Digit Span forward/backward/sequence; LSS/LSD = Letter Span phonologically the same/different; CSF/CSB = Counting Span forward/backward; BOUR = Bourdon-Vos task; TMTA/TMTB = Trail Making Test A/B; TMTRA/TMTRB = Trail Making Test A/B revised; RAV = Raven task.

Table 4 shows that this initial confirmatory model had to be rejected because it did not adequately represent the correlations among the 21 measures. To improve the fit of the model, parameters were added on the basis of residual covariances combined with theoretical considerations. In this second stage of constructing the confirmatory model, correlated errors were allowed among the subscores of the Sternberg task; between Trail Making Test A and B; Trail Making Test B and the revised Trail Making Test A; Digit Span task forward and backward; and among the Simple Reaction Time task, variability in Reaction Time, Blocks compatible and Blocks incompatible. These alterations were theoretically acceptable because the allowed alterations concerned scores between tests of the same type (i.e., test construction and paradigm). The fit of the model improved but still did not reach significance (see Table 4). In the third stage, correlations between Simple Reaction Time and the Sternberg subscores were allowed. Moreover intercorrelations between the Raven task and Trail Making Test B, and the Raven task and the Trail Making Test B revised were allowed. The Sternberg task had a reaction time component. Both original and revised Trail Making Tests B, like the Raven task, had a distinct Central Executive factor, more prominently than both Trail Making Tests A. So these alterations were also acceptable on theoretical grounds. The third and final model has a level of statistical fit represented by χ^2 (162, N = 267) = 179, p = .17. The estimates of psychometric fit are .93 by the normed Bentler-Bonett method (δ) and .99 by the nonnormed Tucker-Lewis method (ρ; see Table 4).

The intercorrelations of the latent factors in the final confirmatory factor model are shown in Table 5. The factor loadings and the uniqueness of variance of the tests are given in Table 6.

To test the possible influence of lead concentration on the latent factors, lead measurements were added to the constructed confirmatory factor model as independent variable. Because 12 lead values were missing, data from 267 subjects were included in the final model. This did not cause changes in the confirmatory model.

Lead concentration did not affect the model when added as independent variable and free to affect all five latent factors. Based on the results of our pilot study (Minder et al., 1994) we expected lead to load highly on the latent factor reaction time. When lead concentration was forced to load on reaction time, lead levels did not affect the model either. This indicates that lead exposure as measured by blood lead concentration does not influence cognitive performance in the children by affecting any of the five latent factors.

Discussion

The aim of this study was to determine whether relatively high blood lead levels, even when they are considered very low, are associated with deficits in cognitive functioning, and, if so, which specific aspects of cognitive functioning are involved. Only 2%

TABLE 4
Stages of Modification of the Confirmatory Factor Model

Stage	χ^2	*df*	*p*	δ	ρ	Extra allowed correlated errors
1	424.4	179	.0	.84	.88	No correlations allowed
2	212.1	168	.01	.92	.98	TMTA-TMTB-TMTRA; DGF-DGB; RT-SDRT; BB-IB.
3	179.2	162	.17	.93	.99	RT-NOR2/4-DEG2/4; RAV-TMTB-TMTRB.

Note. TMTA/TMTB = Trail Making Test A/B; TMTRA/TMTRB = Trail Making Test A/B revised; DGF/DGB = Digit Span forward/backward; RT = Simple Reaction Time task; SDRT = standard deviation Simple Reaction Time task; BB/IB = Block task compatible/incompatible; NOR2/4 = Sternberg task two/four targets undegraded; DEG2/4 = Sternberg task two/four targets degraded; RAV = Raven task; δ = reliability using Bentler-Bonett formula; ρ = reliability using Tucker-Lewis formula.

of the children seemed to have a lead level that was slightly above the American safety standard of 100 microgram lead per liter blood.

Our methodological approach was aimed at increasing the probability of finding any existing correlation between blood lead level and attentional processes in asymptomatic children. An exploratory and a confirmatory factor analysis were performed on the tests in order to obtain robust, aggregated measures of the control and speed aspects of attention. Both blood lead levels and blood lead variance turned out to be very low in our sample. In the confirmatory factor model a higher blood lead level was not associated with any of the factors. The correlation with reaction time expected from the results of the pilot study (Minder et al., 1994) did not show up. In this pilot study we found an age-corrected correlation between simple reaction time and hair lead level. High hair lead levels in the pilot study were also related to less efficient Trail Making Test B performance. The difference between the results of this study and these of the pilot study may be attributable to differences in body lead burden between the groups of children tested. Children in the pilot study all came from a polluted area, whereas the children in this study did not. Unfortunately, the body lead burden of both groups cannot be compared directly because blood lead concentration and hair lead concentration are rather different measures. Moreover, a standard of hair lead concentration is not available. Consequently, there are no means of determining whether the lead burden of the children in the pilot study indeed was rather high or not.

TABLE 5
Latent Factor Intercorrelations of the Final Confirmatory Factor Model

Factor	Phonological loop	Reaction time	Memory search	Perceptual speed	Working memory
1. Phonological loop	1.00				
2. Reaction time	−.28	1.00			
3. Memory search	−.24	.51	1.00		
4. Perceptual speed	.41	−.49	−.42	1.00	
5. Working memory	.82	−.41	−.43	.67	1.00

There is no consensus about which blood lead level in children is safe. The Centers for Disease Control (1991) advisory committee states that in children even blood lead levels lower than 100 μg/L may cause adverse effects. Likewise, Tesman and Hills (1994) conclude that "no level of lead in the body may be viewed as safe" (p. 13). In contrast, Smith (1989) and Sayre and Ernhart (1992) among others suggest that, because of methodological problems, it is not possible to ascertain that low levels of lead affect cognition or behavior in children. The children in this study were selected in such a way that, if an effect of lead on cognition were present, it would have a high chance of being found, and cognition was measured in a detailed way.

Conclusion

This study does not support the hypothesis that lead at doses below 100 μg/L affects memory or attention in 9- to 12-year-old boys. Of course, no conclusions are possible about long-term effects.

Blood lead levels were higher in children with lower socioeconomic status, in children with more hand-to-mouth behavior, and in spring and summer. However, there is no reason to be concerned about the body lead burden of 9- to 12-year-old boys in the Netherlands, because overall lead levels were rather low, and no cognitive effect of lead could be demonstrated in these children, although they were selected to maximize the probability of finding an effect if there were one.

ABOUT THE AUTHORS

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TABLE 6
Factor Loadings of the Tests in the Final Confirmatory Factor Model

Test	Phonological loop	Reaction time	Memory search	Perceptual speed	Working memory	Unique variance
	Factor					
NOR2	—	—	.87	—	—	.23
DEG2	—	—	.87	—	—	.23
NOR4	—	—	.76	—	—	.41
DEG4	—	—	.69	—	—	.53
RT	—	.67	—	—	—	.55
BB	—	.89	—	—	—	.22
IB	—	.89	—	—	—	.21
SDRT	—	.35	—	—	—	.88
DGF	.66	—	—	—	—	.57
DGB	—	—	—	—	.59	.65
LSS	.73	—	—	—	—	.47
LSD	.77	—	—	—	—	.41
DGS	.63	—	—	—	—	.60
CSF	—	—	—	—	.61	.62
CSB	—	—	—	—	.51	.74
BOUR	—	—	—	.47	—	.78
TMTA	—	—	—	−.54	—	.71
TMTB	—	—	—	−.61	—	.62
TMTRA	—	—	—	.83	—	.32
TMTRB	—	—	—	.80	—	.36
RAV	—	—	—	—	−.33	.89

Note. NOR2/DEG2 = Sternberg task, two targets undegraded/degraded; NOR4/DEG4 = Sternberg task, four targets undegraded/degraded; RT = Simple Reaction Time task; BB/IB = Block task compatible/incompatible; SDRT = standard deviation Simple Reaction Time task; DGF/DGB/DGS = Digit Span forward/backward/sequence; LSS/LSD = Letter Span phonologically the same/different; CSF/CSB = Counting Span forward/backward; BOUR = Bourdon-Vos task; TMTA/TMTB = Trail Making Test A/B; TMTRA/TMTRB = Trail Making Test A/B revised; RAV = Raven task.

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AUTHORS' NOTES

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